BooNE MC status,   March 4 2016

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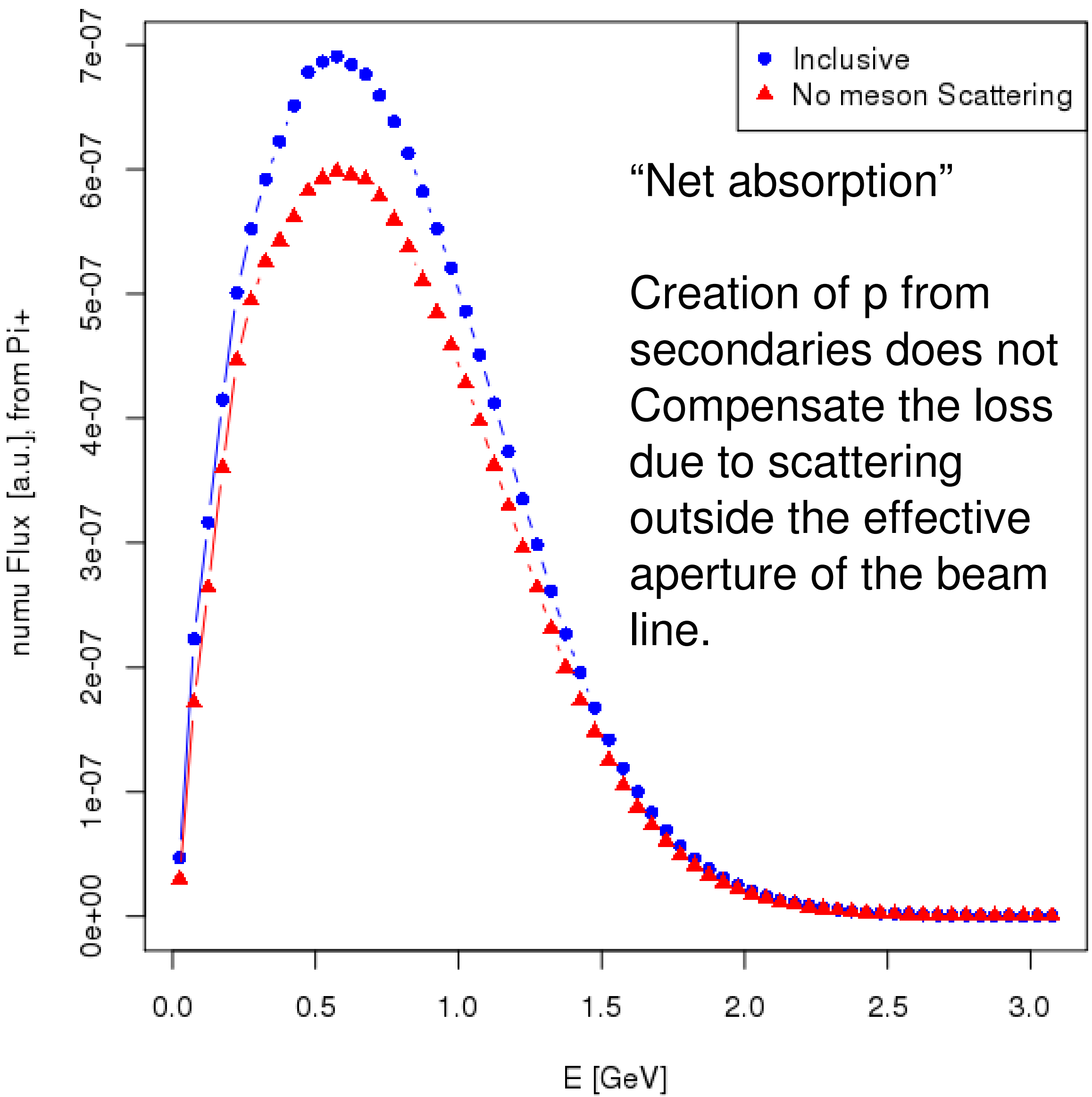
The issues to be resolved..

- A few details on checking the pion-scattering cross-sections and there use, should they become negative.
- The results from the special runs where all pions that are subjected to a hadronic (or unrecognized as EM.) process are stopped. This should produce a ν_μ beam (from pion decays) that has no uncertainty from hadronic models and cross-sections.
- An explanation is given: The step length and energy loss model (G4 v4p8 vs v4p9) have changed. This last changed has a surprisingly large effect on the pion energy spectrum measured after the horn.
- (A few details on the impact of a change in mean step length on the simulated interaction rates are also given, – if time permits)

Shown on Feb. 19 2016



"Net absorption"

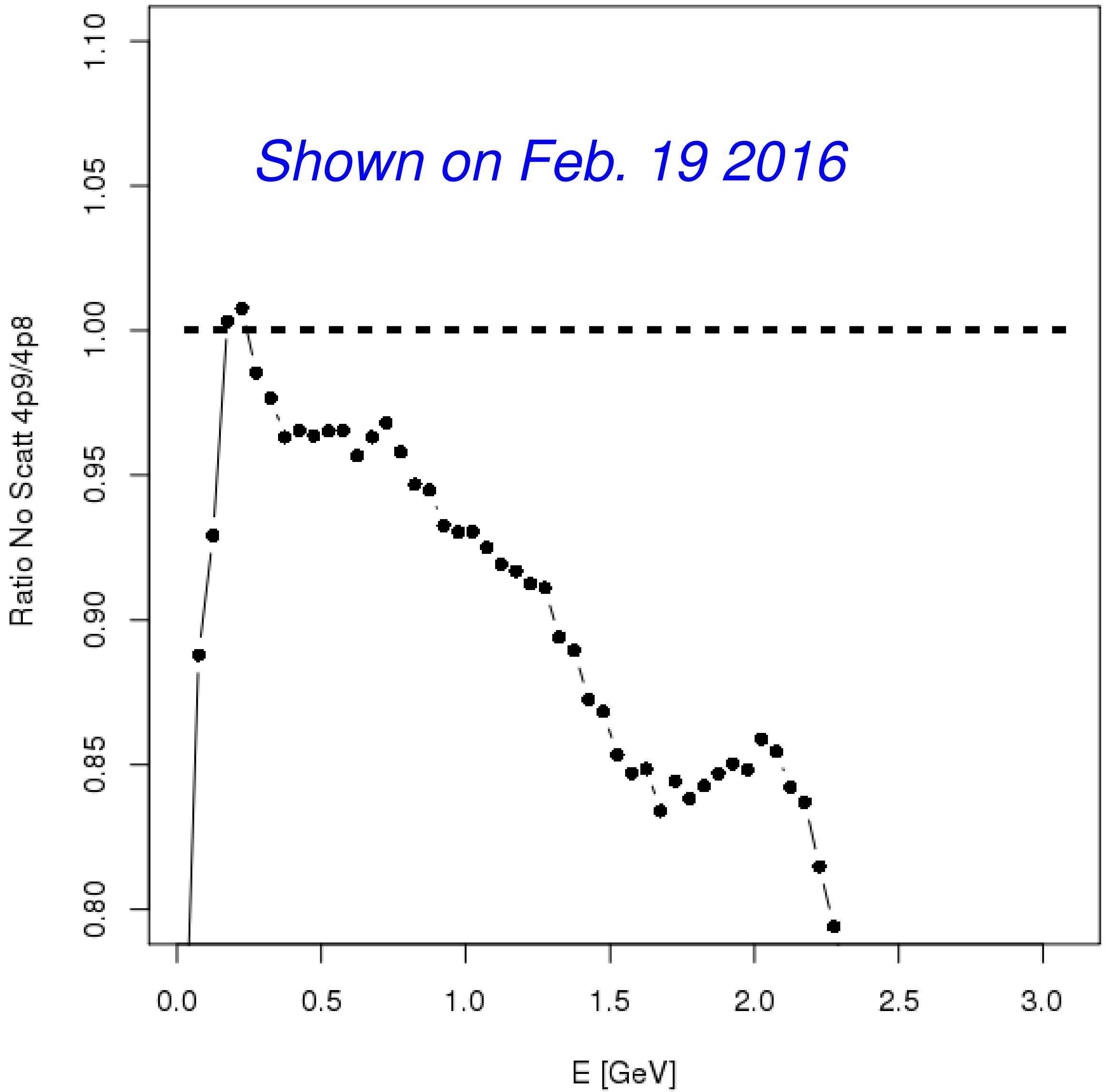
Creation of p from secondaries does not Compensate the loss due to scattering outside the effective aperture of the beam line.

This the neutrino flux from $\pi^+ \rightarrow \mu^+ \nu_\mu$ obtained with G4, v4p9

"Inclusive" means we include all pions, whatever their ancestry might be.

"No scattering" means that, if the parent of the pion is not the primary proton, we exclude the Neutrino. This was first implemented in the Dk2Nu post-G4 processing.

We now implement this algorithm in the BooNEG4Beam itself, such that the implementation can be "back-ported" to v4p8, without modification of BooNEBeamNT code.



This the ratio of the “No Scattering” neutrino fluxes, $\pi \rightarrow \mu\ \nu_\mu$ only, V4p9/v4p8

This is with the full geometry.

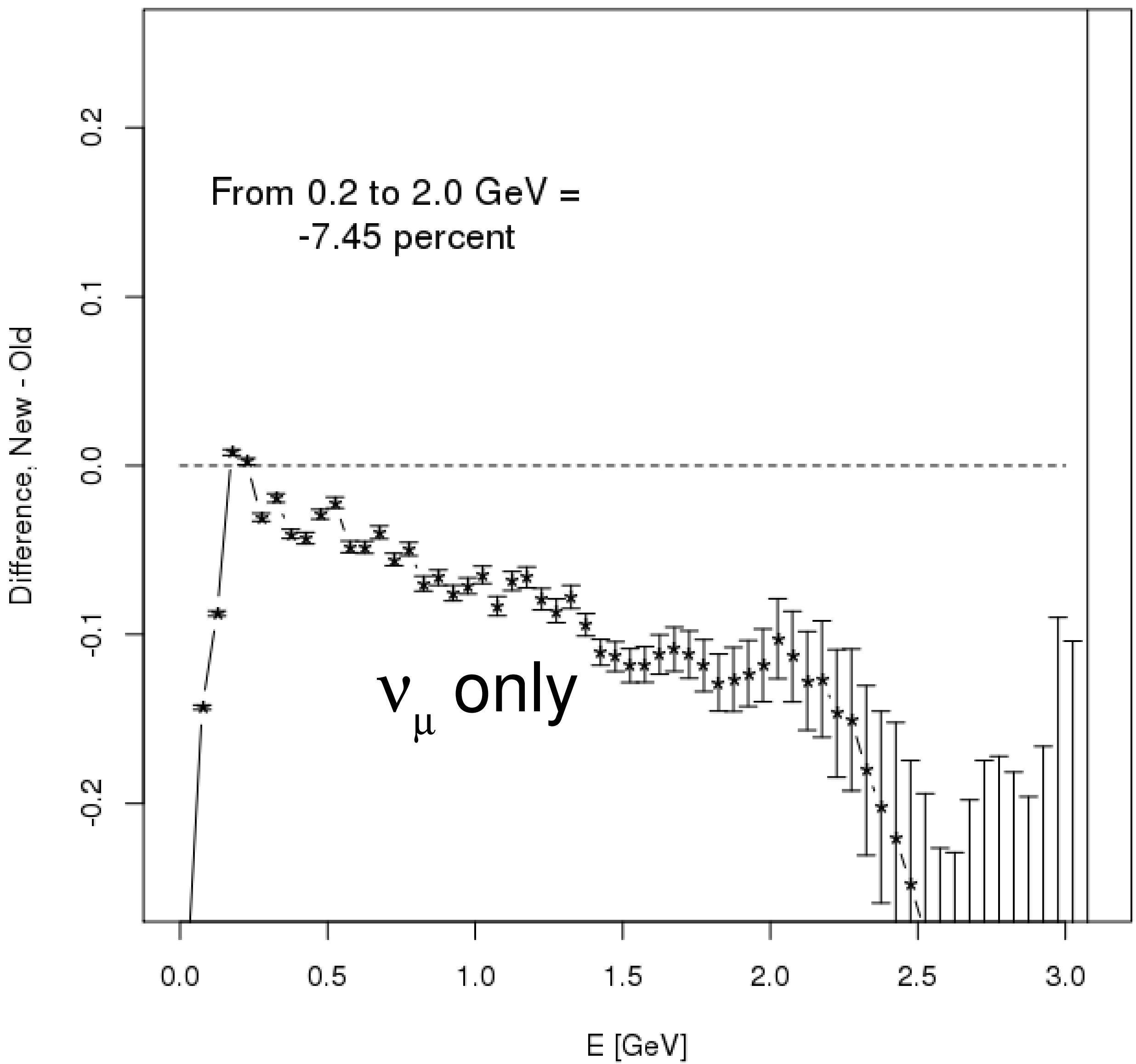
Inclusively, we have ~ 8% difference (see next slide)

Not what we predicted, 2 weeks ago..

(I had reservation about that prediction, but was not expecting such a large effect either...)

O.K., this is worth investigating.

Benchmark ν_μ flux, Thick target, V4.8 vs 4.9



In the previous plot, we had only one slug of Beryllium. In addition, no material in the horn, collimator, air... Same geometry, same magnetic field, just no interaction downstream of that 1rst Be slug.

For this plot, we now restore the full geometry.

In both versions,G4 v4.8.1 and v4.9.6

Shown on Jan 6 2016..
No change in the BooNEG4Beam code since then !..

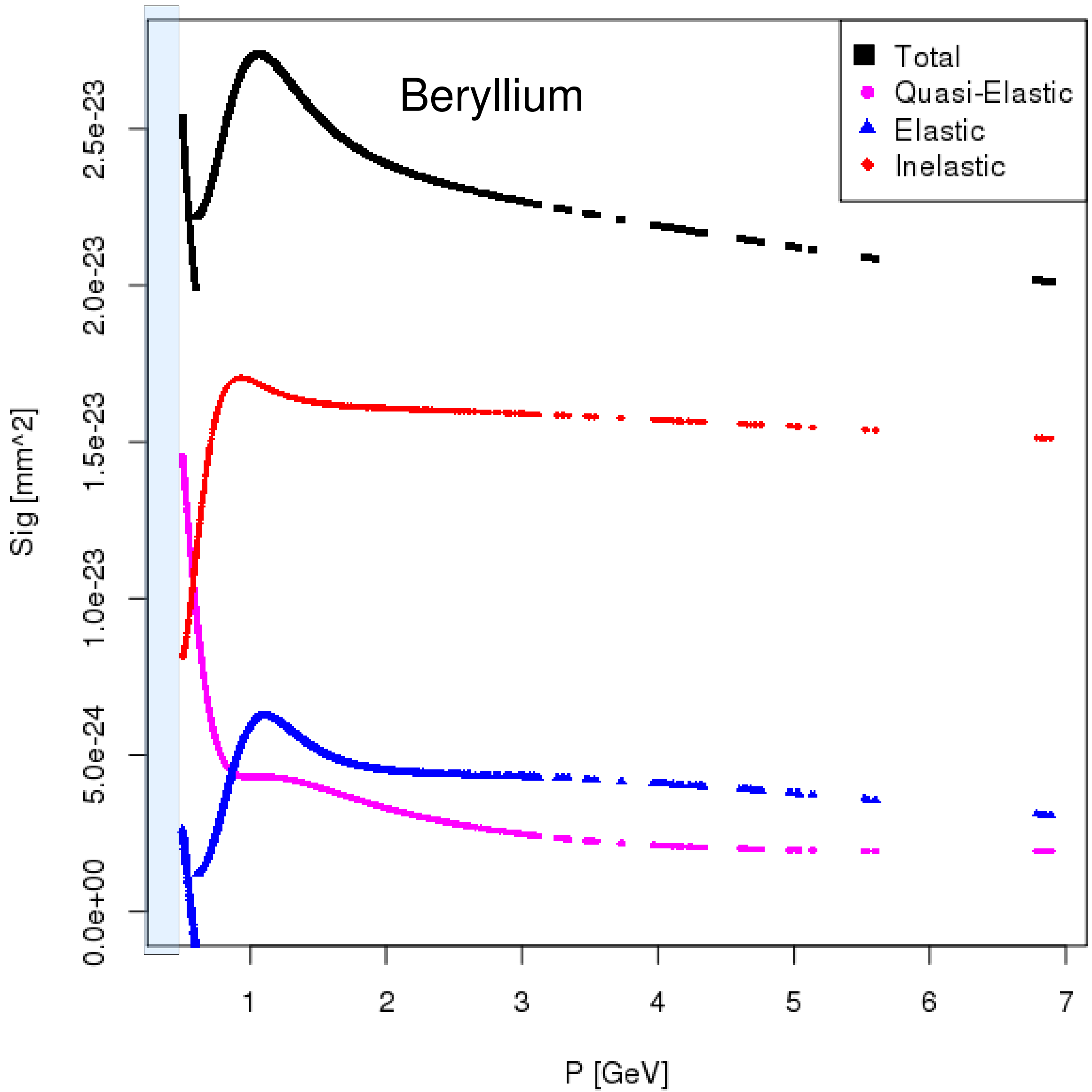
Investigating the “No Pion Scattering ratio, v4p8/v4p9”

- Compare the two codes. On average, if, (and only if),
  - The 6D momentum phase space for the p-> Be π^+ + X are identical
  - The mean free path for all hadronic processing processes are identical, for all tracking medium, over the entire momentum range
  - The average track length in a given tracking medium are identical
- Then, this ratio should be 1 (within statistics).
- Reviewing the above conditions..
  - Forgot to mention that the energy loss also changed!.
  - The change in the mean step length could also matter (smaller effect)

On Mean free paths..

- If all hadronic total X-sections are identical, then, the hadronic mean free paths should be identical
  - Should be true for π^+ on Beryllium and Aluminium, since BooNEG4Beam "overwrites" (overloads, in C++ terminology) the native G4 cross sections. This, for pion momenta between 0.5 and 11 GeV
  - This overload is applied only to "Elastic" and "Inelastic" processes.
  - MiniBooNE proponents added a third process, "Quasi-Elastic". This is strictly a "User" process. (own cross-section, own model).
  - No "simple-minded" double counting occurs. Note that the "Elastic" cross sections is obtained by subtracting the Inelastic & Quasielastic from the total cross-section.
- However, all this does not apply to scattering in steel (collimator, tunnel walls..) !..

Checking the BooNE p scattering X-sections.

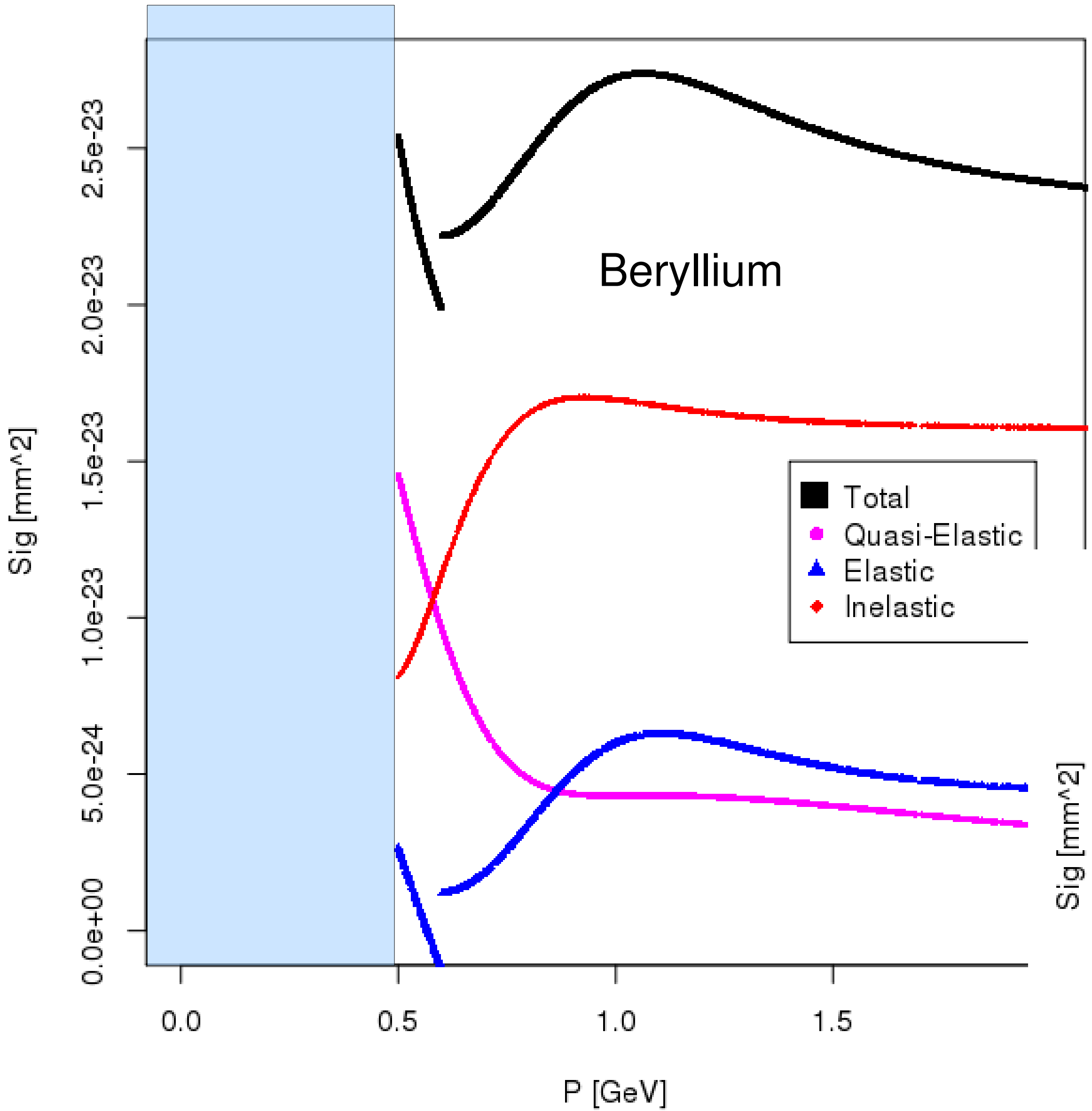


This is a graphical rendering of BooNEHadronCrossSections Class.

They are not used below 0.5 GeV. The code reverts back to the native G4 values.

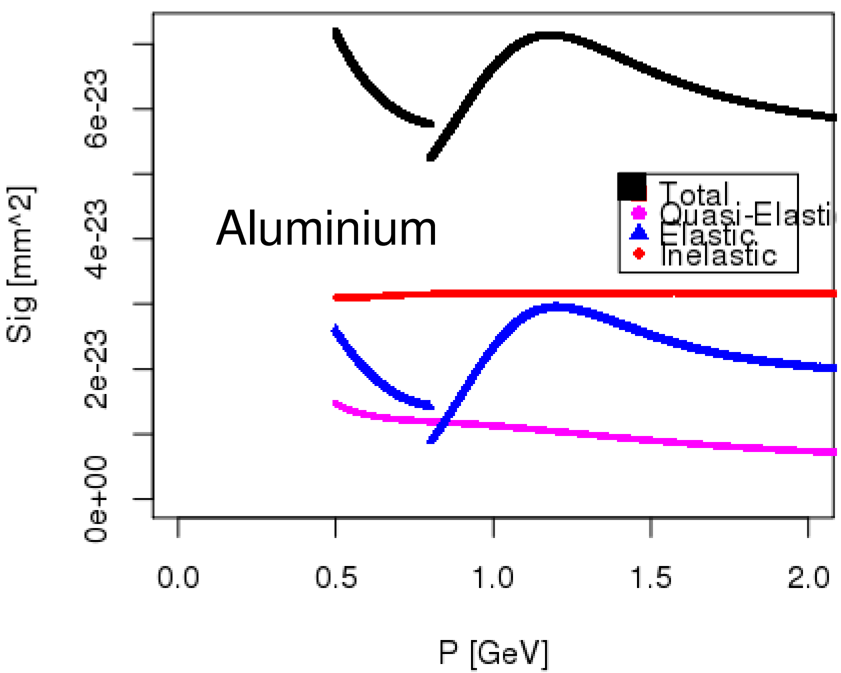
This class gives identical results under BooNEG4Beam v4p8 and v4p9.

Shown two weeks ago...
Except that I slightly re-adjusted the shaded rectangle.
Indeed, there are no entry below 0.5 GeV, because the BooNECrossection are no applicable below 0.5 GeV.



A better plot, showing the low energy behavior.

Yes, the elastic cross section is negative. (For Al, small but positive.

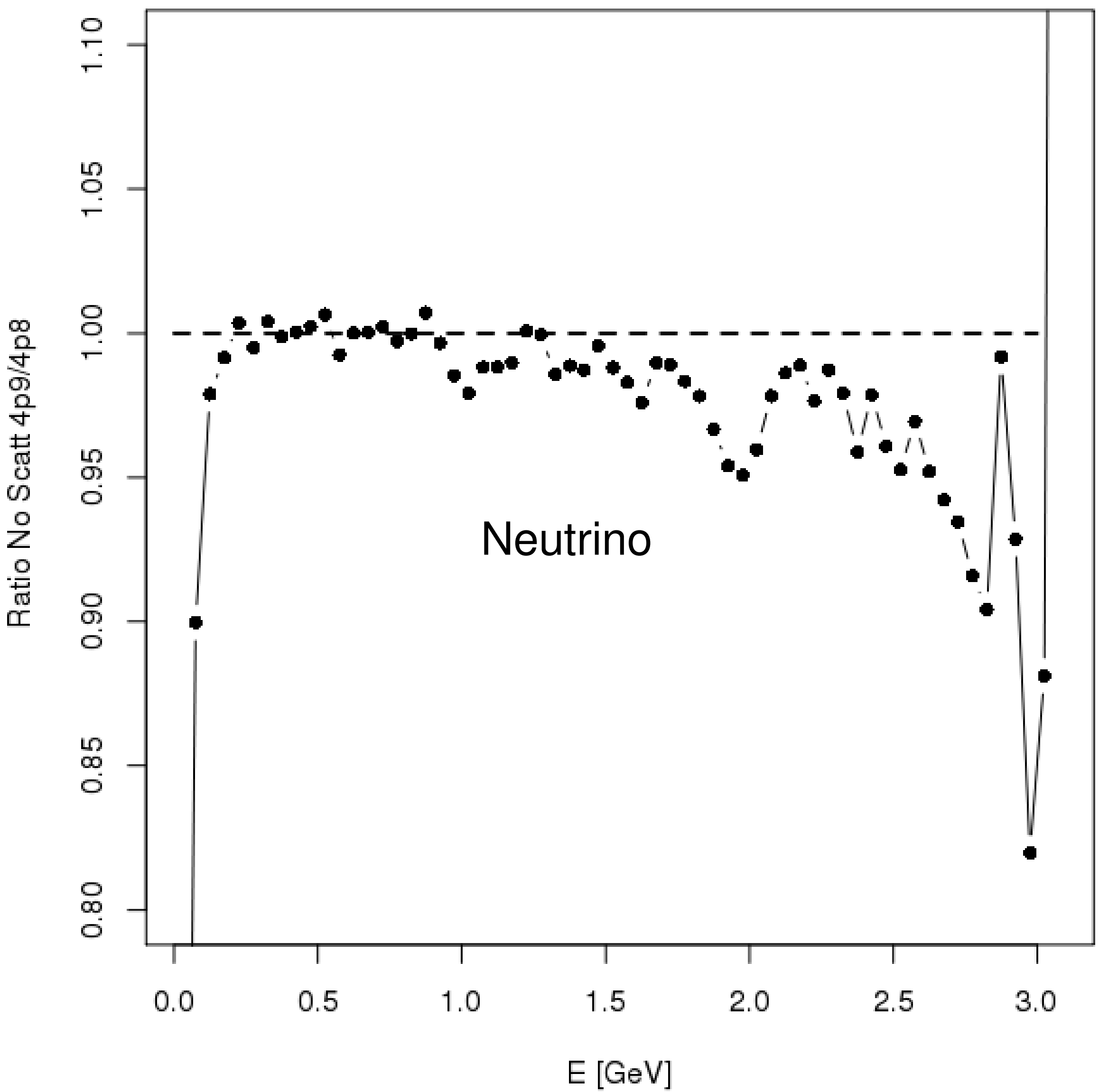


The good news: In both version of Geant4, should the cross-section be negative, the corresponding mean free path is set to a very large value.

==> same thing as for a negligibly small value.

Let us be systematic, and investigate the ν_μ flux for 1 Be (shown last time), 3 Be Slug, and Full target + Horn Alum, rejecting all meson scattering from the sample. We will also shown the pion energy spectrum after the horn.

The ν_μ flux with one slug, all scattered hadrons are removed. ..



We still do have a problem, well above 0.5 GeV !

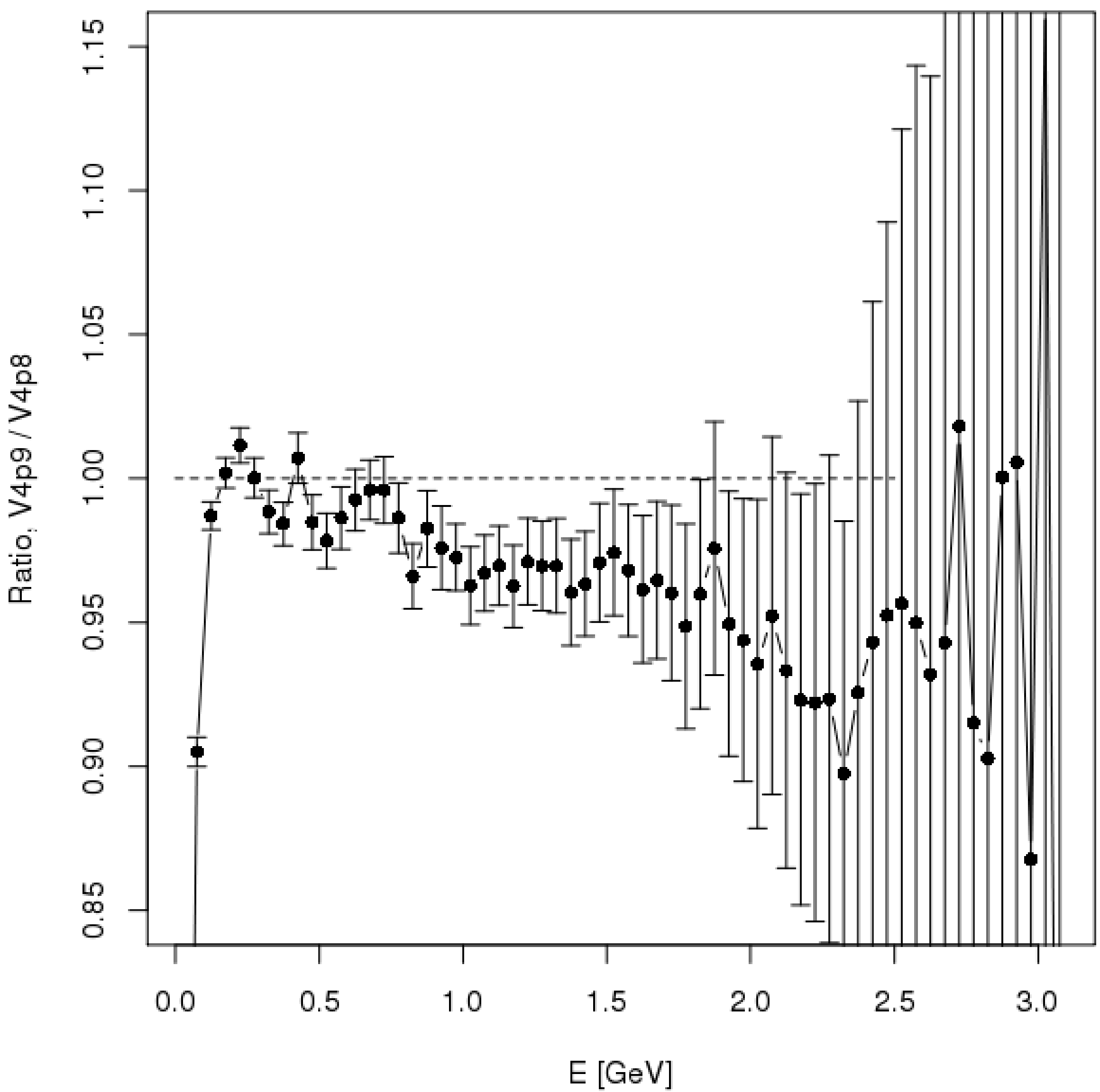
Of course at ~0.25 GeV, the calculation becomes very sensitive to the value of the (large!) QE X-scattering, as the native hadronic X-sections changed

I don't have an explanation for this effect!...

Shown last time..

This time, I' ll giving you a (distressing) explanation...

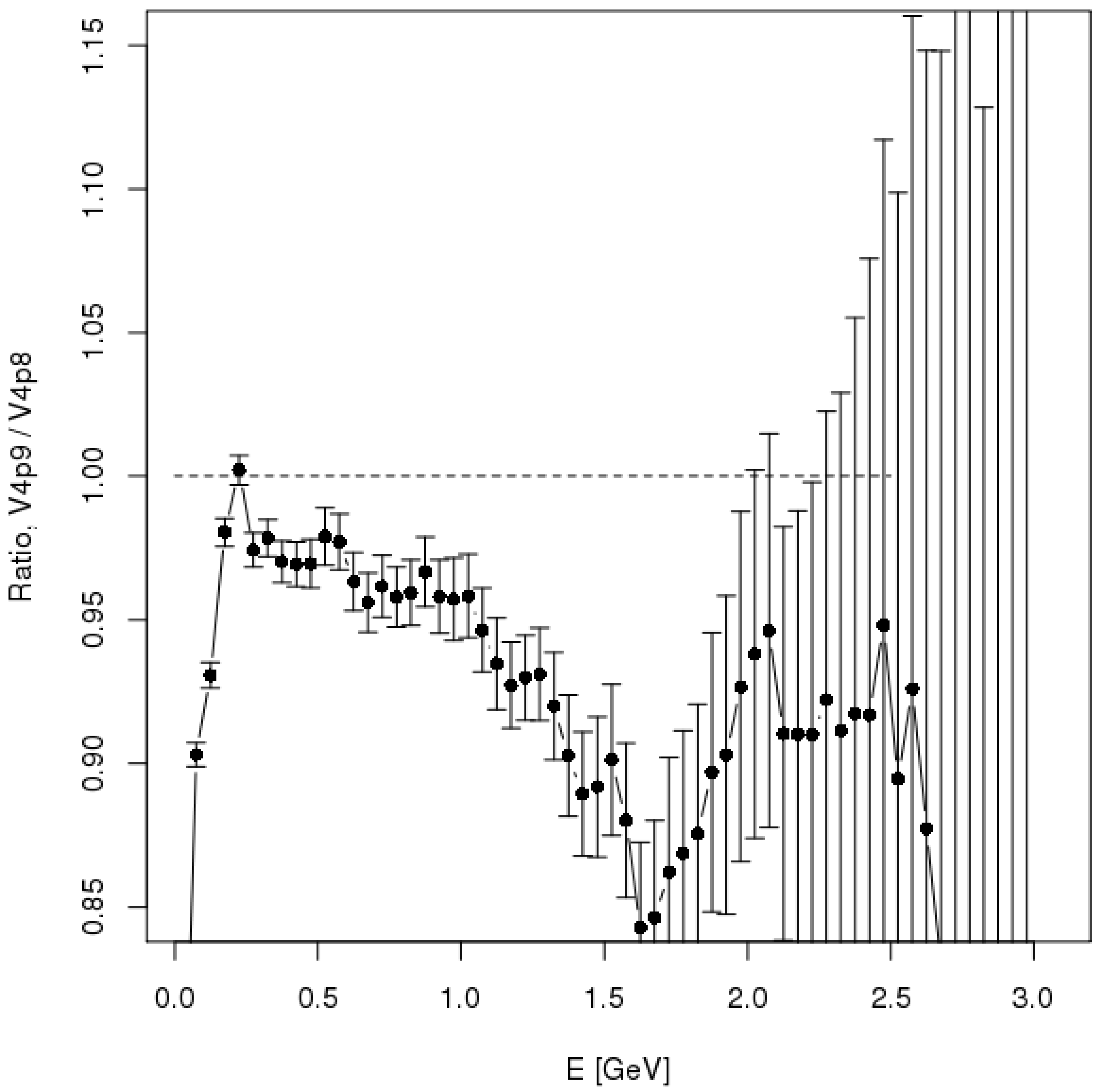
The ν_μ flux with Three slug, all scattered hadrons are removed. ..



A bit bigger, if any.

As expected if the effect is ~ proportional to the amount of material traversed.

The ν_μ flux with the target, the horn, no other material

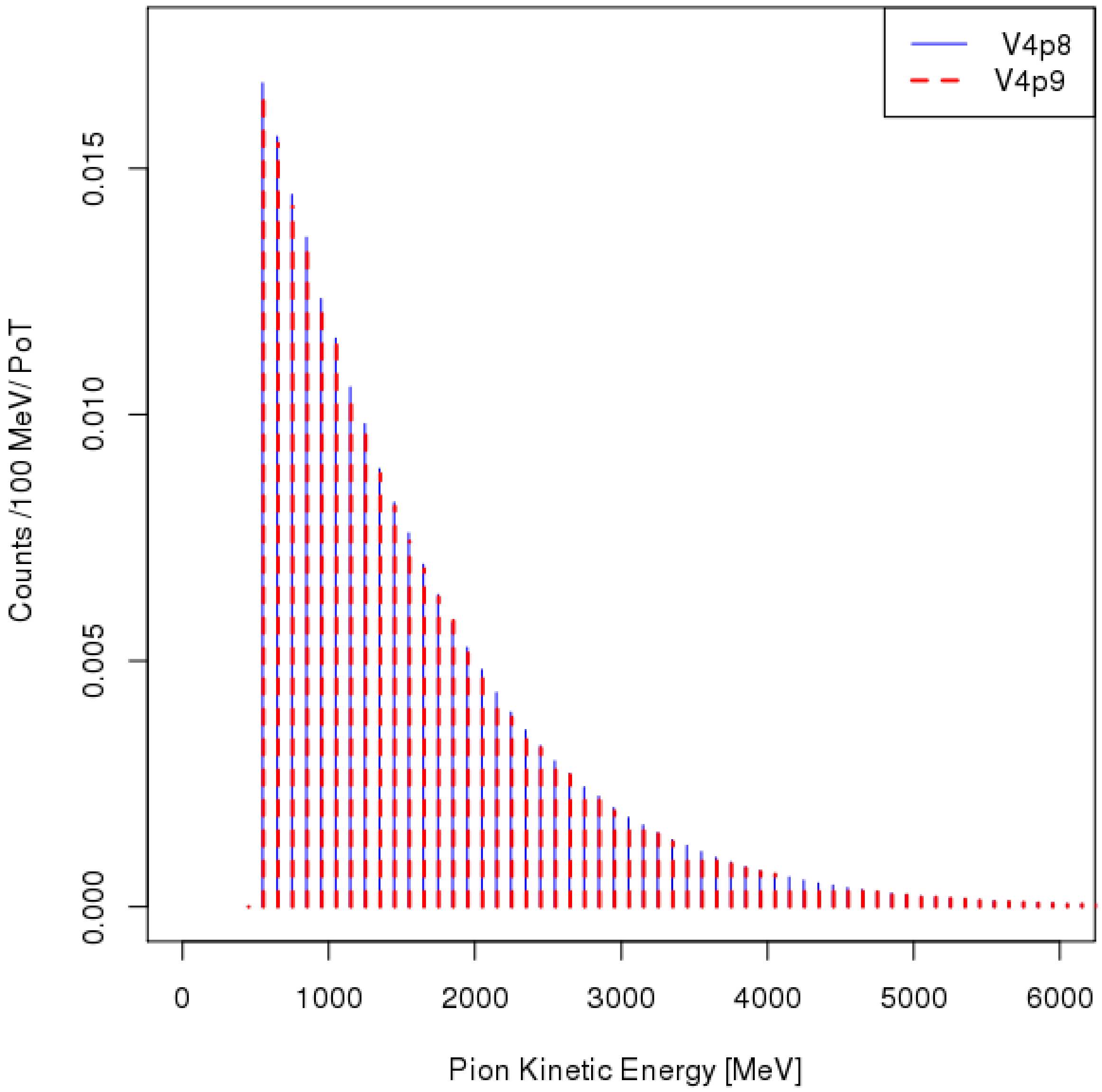


An yet bit bigger !.

Back one step: Let us look at the pions kinectic energy above 0.5 GeV, measured at the horn.

Again, clean pions, always coming directly from the primary vertex.

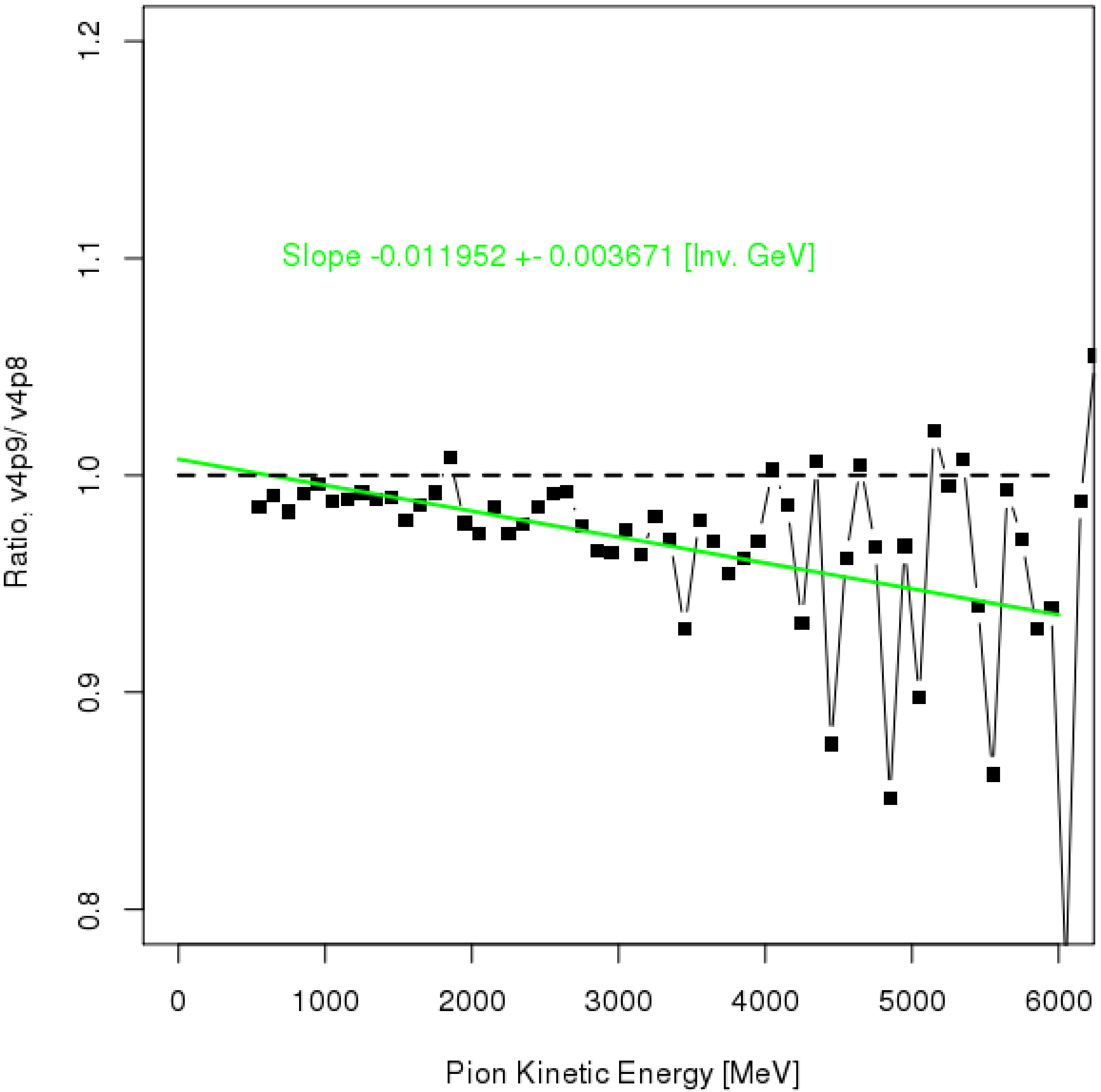
The π^+ flux with three slug, all scattered hadrons are removed. ..



These are the distributions of the pion kinetic energy, above 500 MeV, measured at the end of the horn.

Very similar, yet, a bit different:

The π^+ flux with three slugs, all scattered hadrons are removed. ..

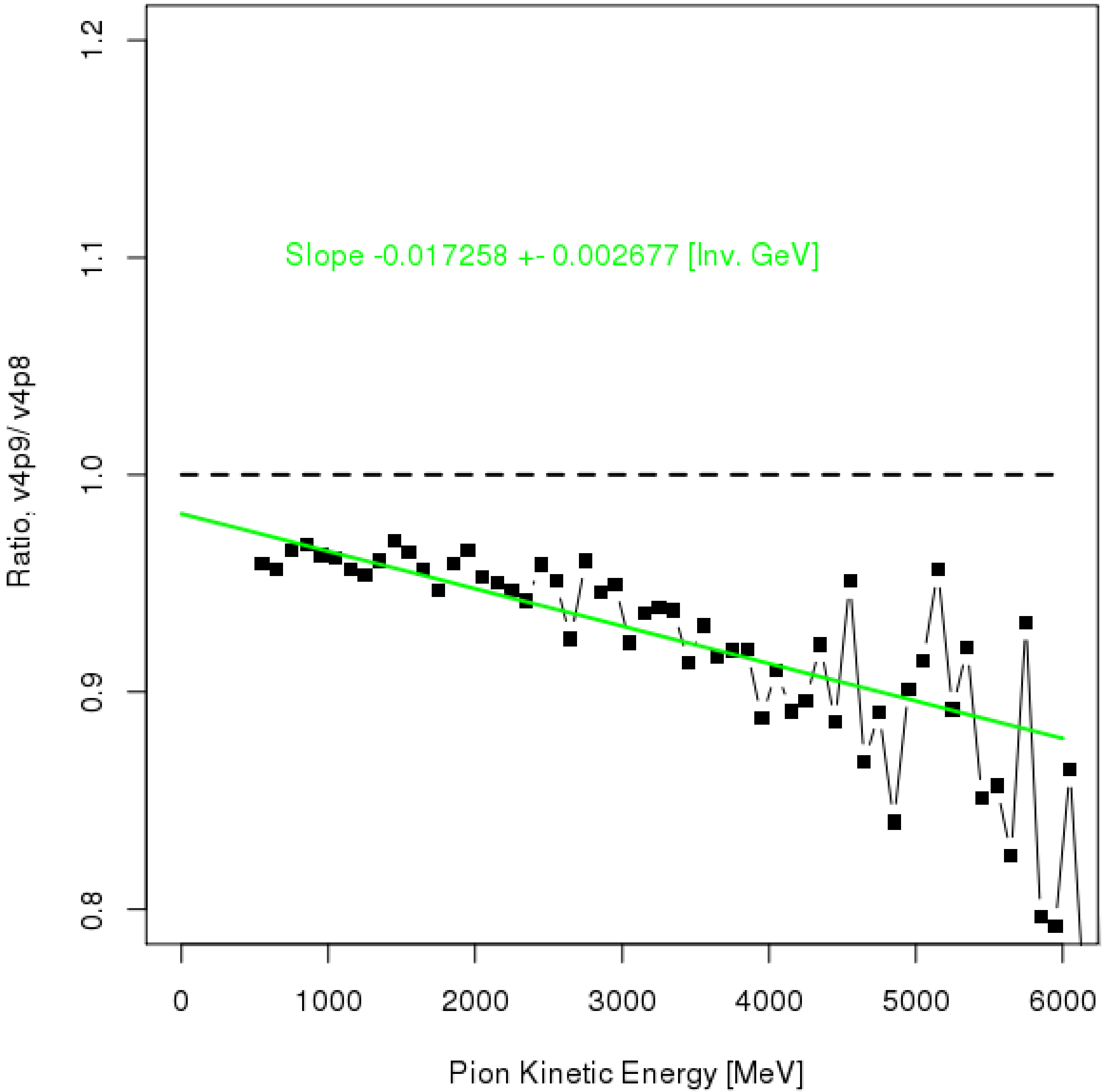


Taking the ratio of the above histogram.

Just a straight line fit, slope is different from 0 at a confidence level of 1.810^-3.

Fitted value at 2.5 GeV (which corresponds to a ν_μ energy ~ 1.0 GeV) is : -2.3 %

The π^+ flux with complete target + Horn aluminum, all scattered hadrons are removed. ..

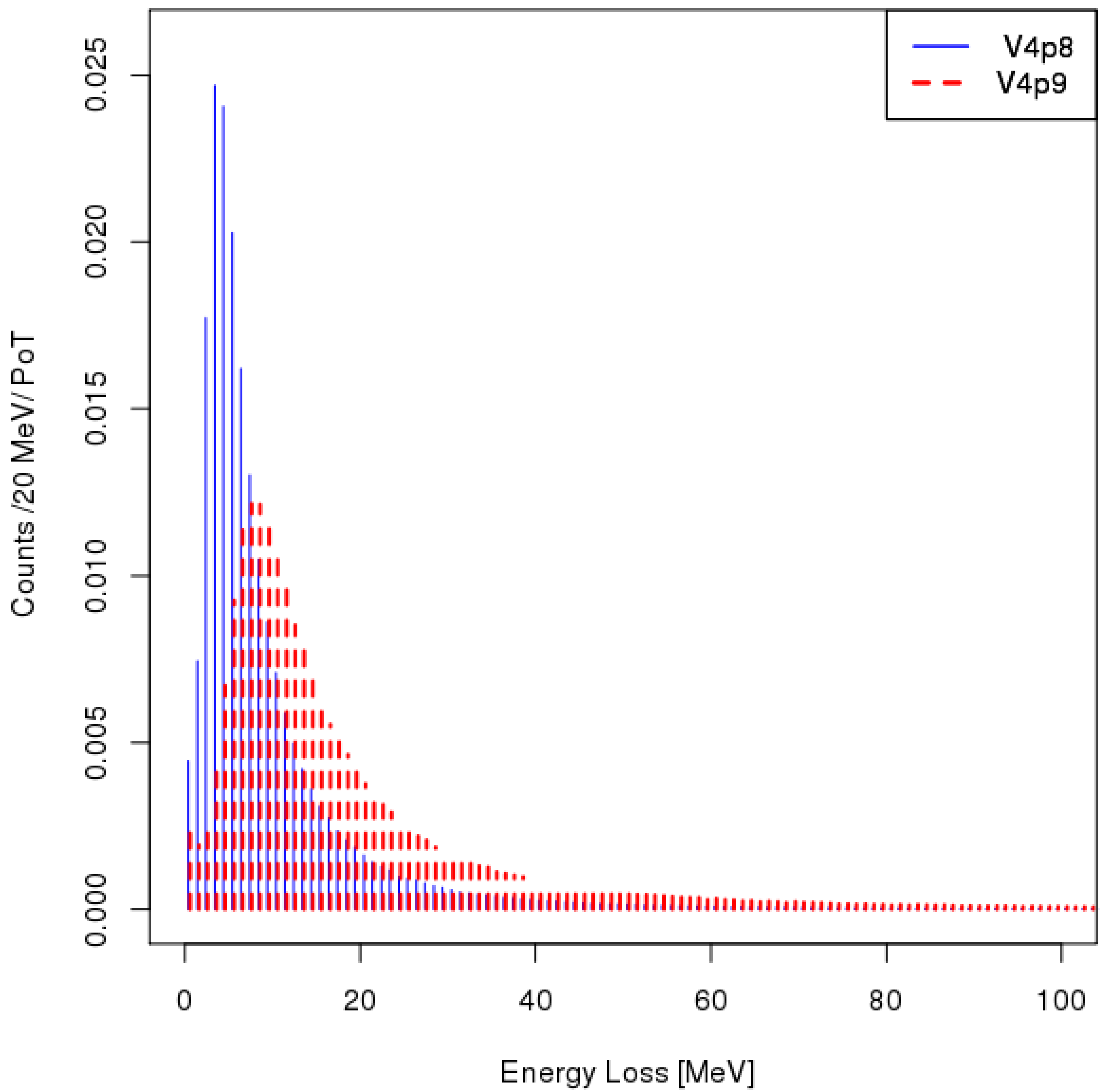


Taking the ratio pf the above histogram.

Just a straight line fit, slope is different from 0 at a confidence level of 1.810^-3.

Fitted value at 2.5 GeV (which corresponds to a ν_μ energy ~ 1.0 GeV) is : -6.1 %

A forgotten change, v4p8 → v4p9 : Electronic Energy loss



Histogram of the energy loss for pion from the primary vertex, through 3 Be Slugs.

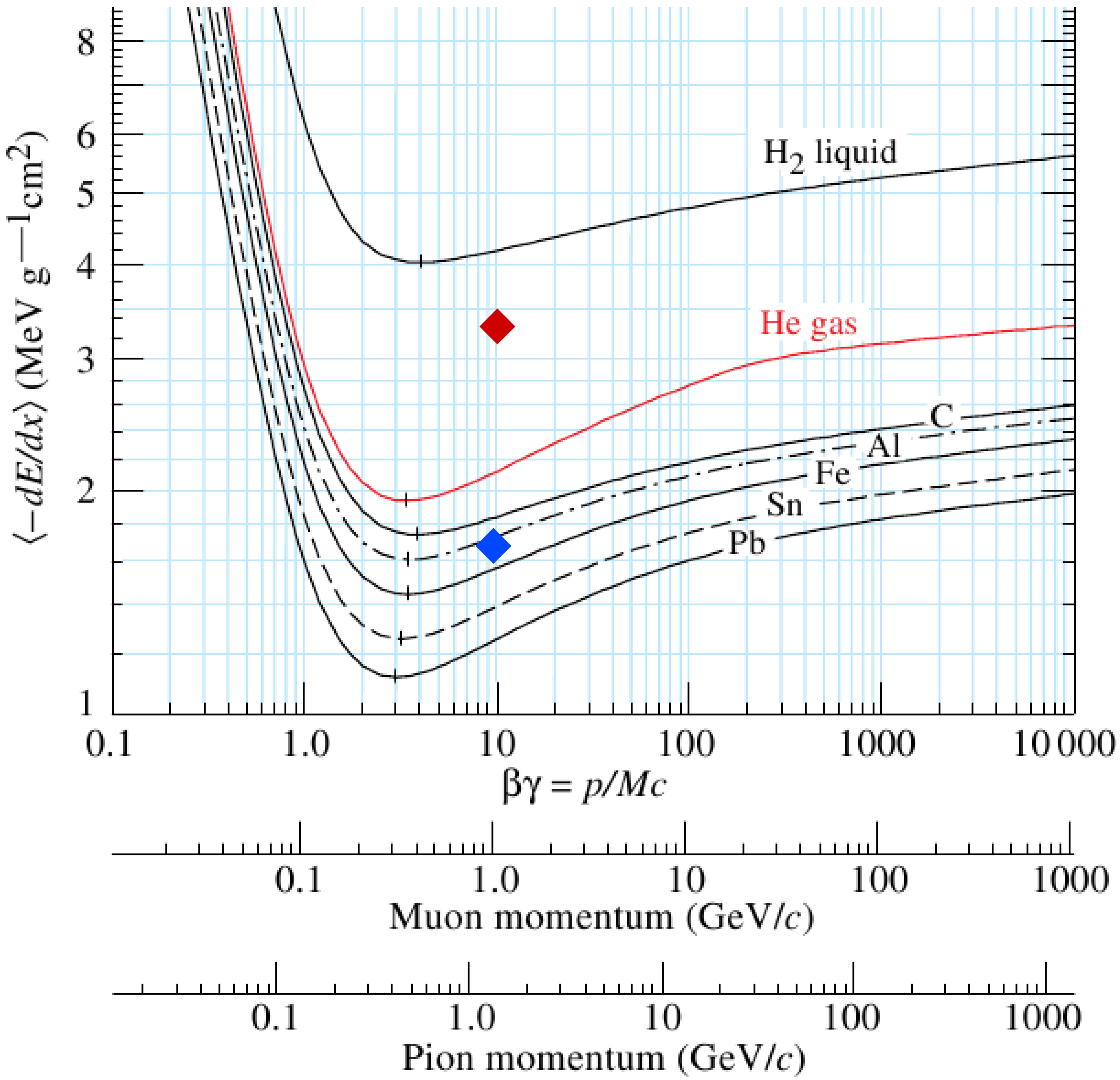
Mean Energy Loss through this (partial) target : 9.6 MeV (v4p8), 19.2 MeV (v4p9)

From this data : mean de/dx:

V4p8 : 1.68 MeV/gr x cm^2
V4p9 : 3.3 MeV/gr x cm^2

For a mean γ factor of 12.6 (mean kinetic energy of 1.5 GeV).

PDG Values: … (2014 edition..)



V4p8 : too low

V4p9 : very likely too high..

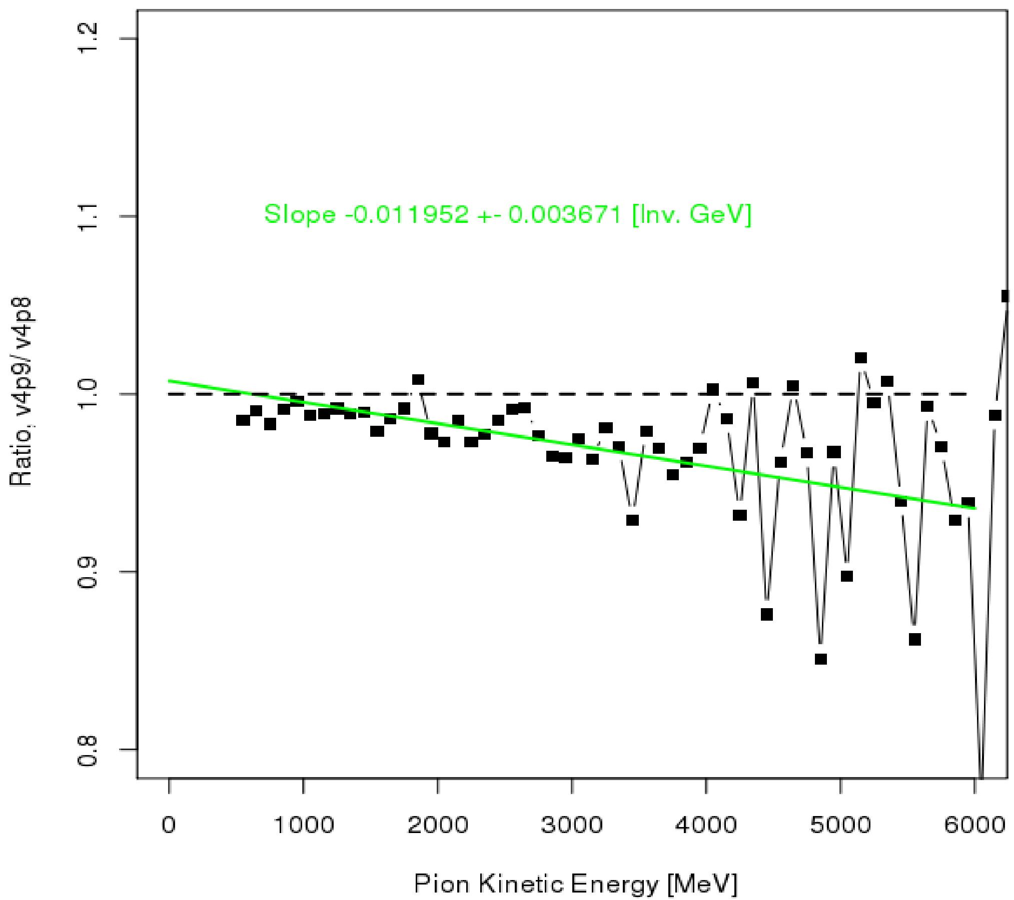
Mean track length is only 30.4 mm (for both versions)

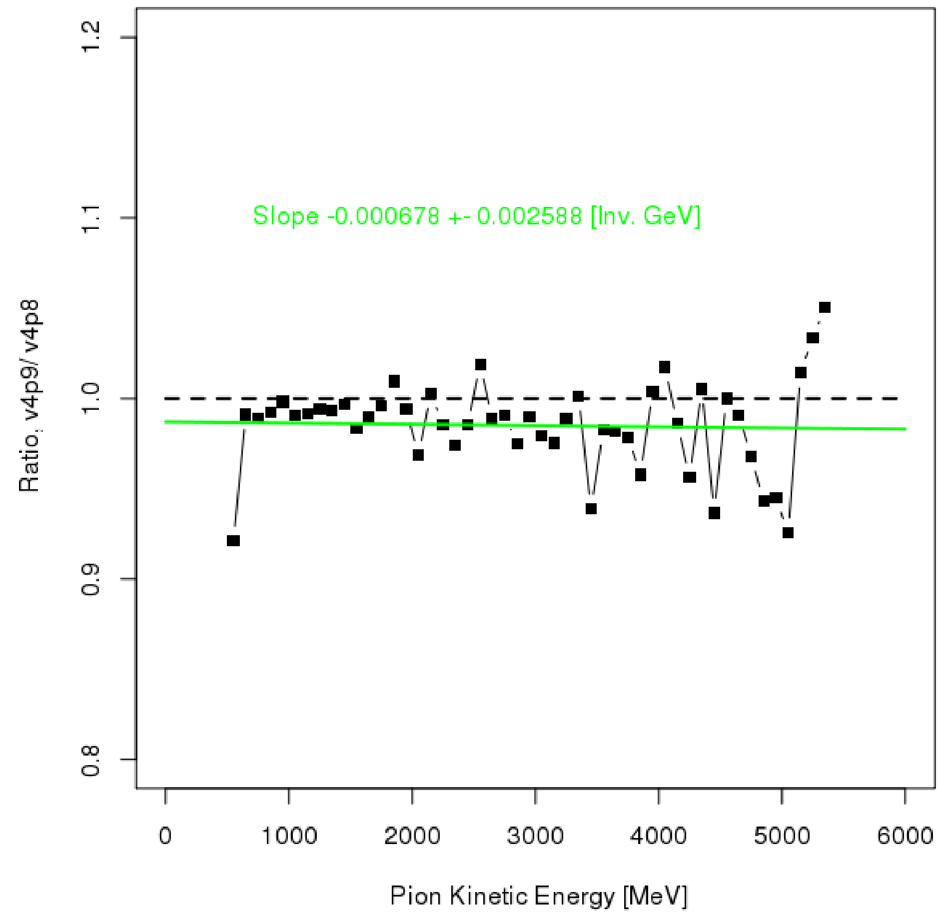
Rejecting the tails of de/dx dist. Does not resolve the issue.

???? Note: almost a clean factor 2 difference ??????

To be investigated ….

The π^+ flux with three slugs, all scattered hadrons are removed. ..





Ratio of π^+ kinetic energy histogram, after horn (shown previously …)

Ratio of π^+ kinetic energy + energy loss in Be That is, the energy at the primary vertex. The slope is gone …. Check of consistency of the pion momentum consistency at primary vertex

??? HadronIonizationProcess done twice. ??

Yes, G4 v4.p8 and v4p9 has no problem, if we (implictly!) ask for it in the Physics List declaration, the energy loss process will be invoked twice.

This implicit invocation is actually version dependent.. Not done in v4p8, done in v4p9. G3 PhysicsList not backward compatible, version dependent. User-Physics List strongly discouraged in v4.10, not supported....

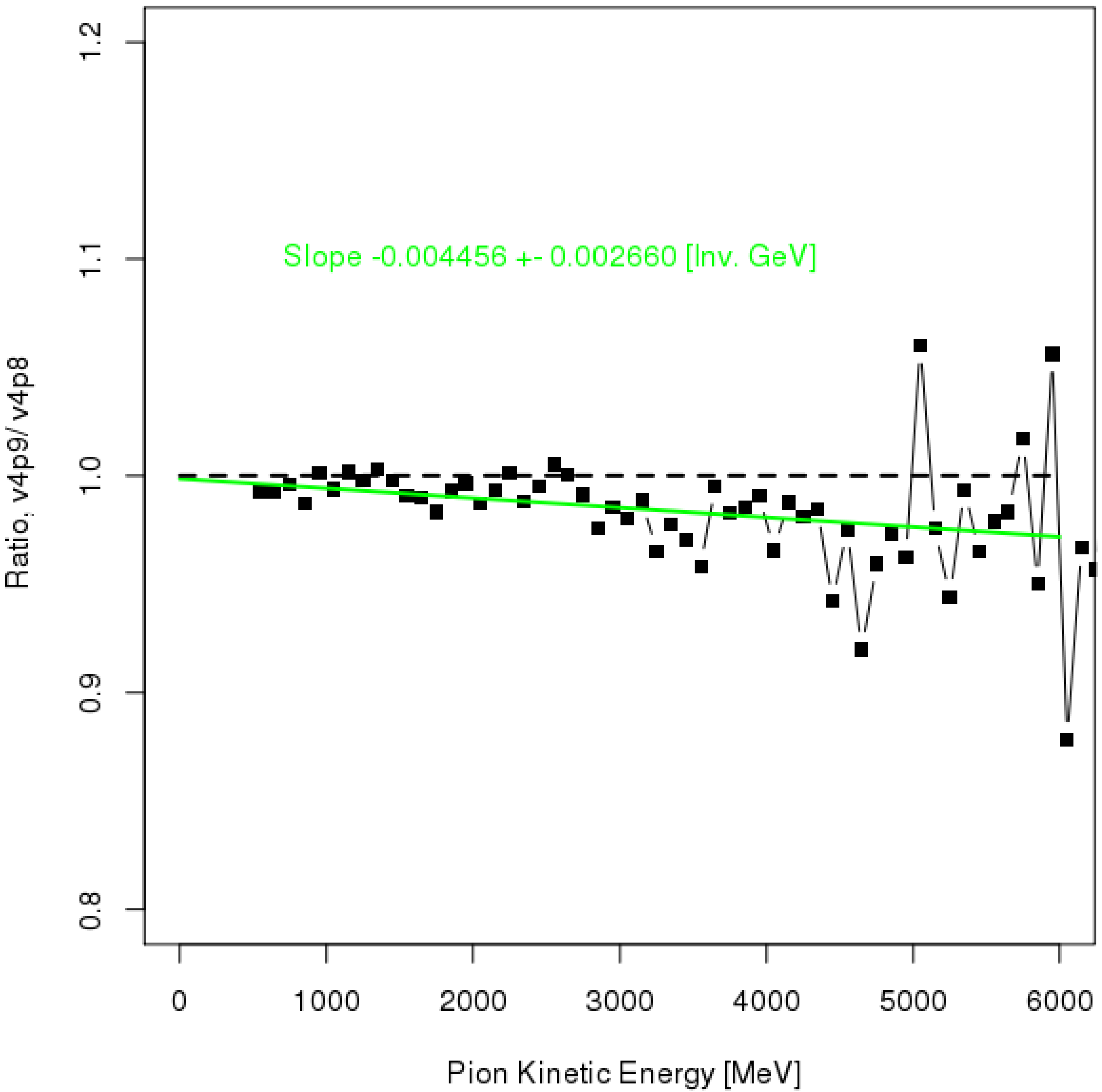
The first real (non-diagnostic related) change in the v4p9 code in the last ~9 months
The change is in BooneHadronPhysics.cc

```
 // use BooNE Cross Sections if asked to
 if(crossSectionsBooNE)thePionPlusInelastic.AddDataSet(&theInelasticData);

 SetSecondaryInteractionModels(ipiplus, theLEPionPlusModel,
                               theBertiniPionPlusModel,
                               NULL,
                               theZeroPionPlusModel);

 pManager->AddDiscreteProcess(&thePionPlusInelastic);
//
// Ionization energy loss seemingly done twice.... P. Lebrun, March 1 2016
//  pManager->AddProcess(&thePionPlusIonisation, ordInActive,2, 2);
```

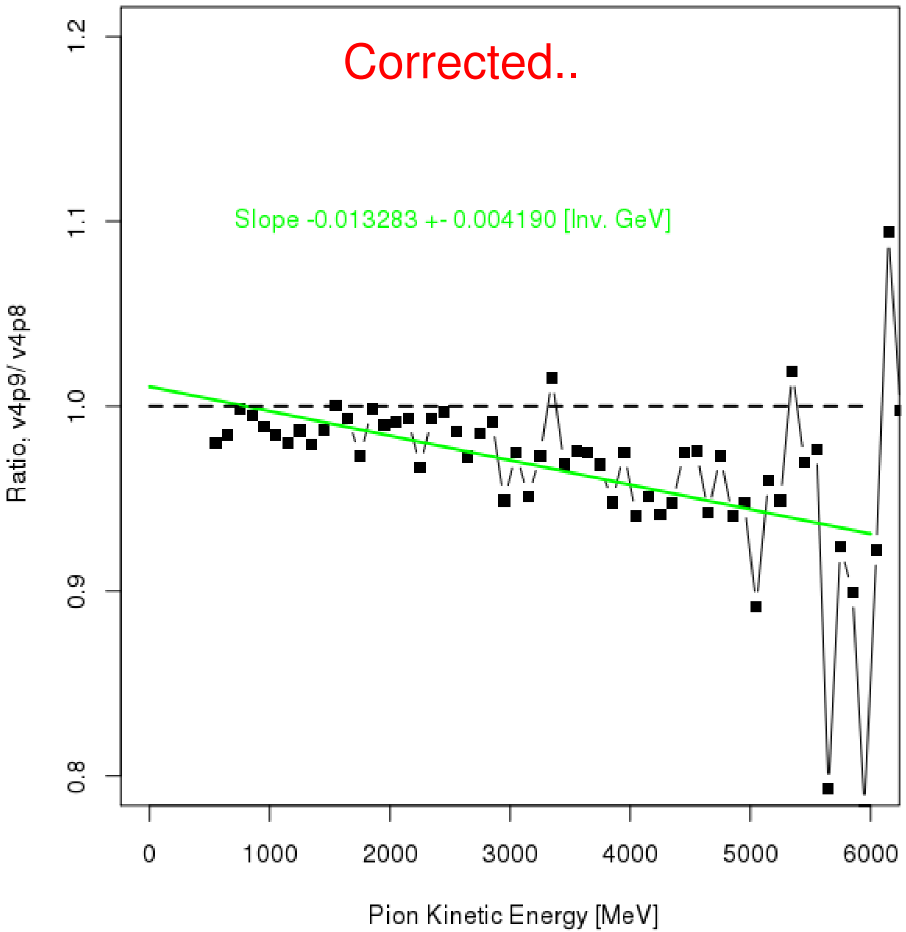
The π^+ flux with three slugs, all scattered hadrons are removed, After removing the 2nd invocation of energy losses.



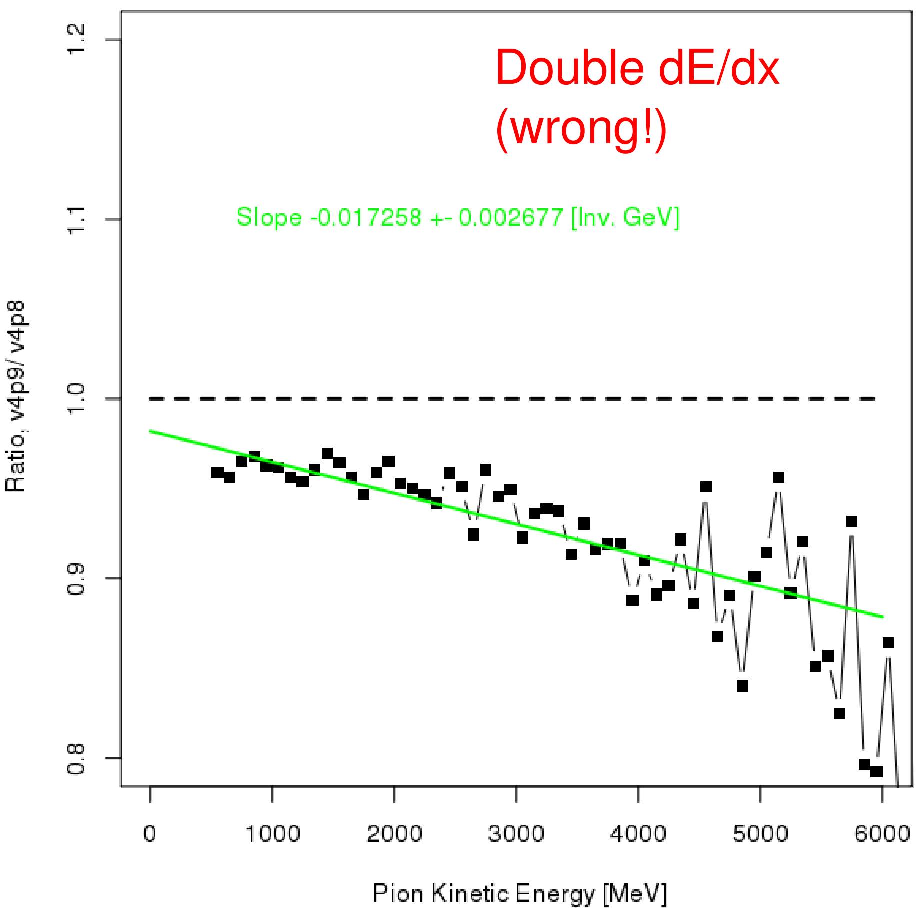
Again, taking the ratio v4p9 (corrected) to v4p8
Just a straight line fit, slope is different from 0 at a confidence level of 1.810^-3.
Fitted value at 2.5 GeV (which corresponds to a ν_μ energy ~ 1.0 GeV) is : -1.25 % (was -2.3 % before)

~ 1% difference. Note :
<de/dx>, 3 BeSlugs: 9.6 MeV
DN/de (π^+) ~ e-(e/9600)
Where e is the π^+ kinetic energy (MeV) See slide 16
So, if we have as shift of 9.6 MeV, expect about 0.9% rate change, over 1 GeV..

The π^+ flux with complete target, Horn Aluminium
After removing the 2nd invocation of energy losses.



The previous fit was (slide 18)

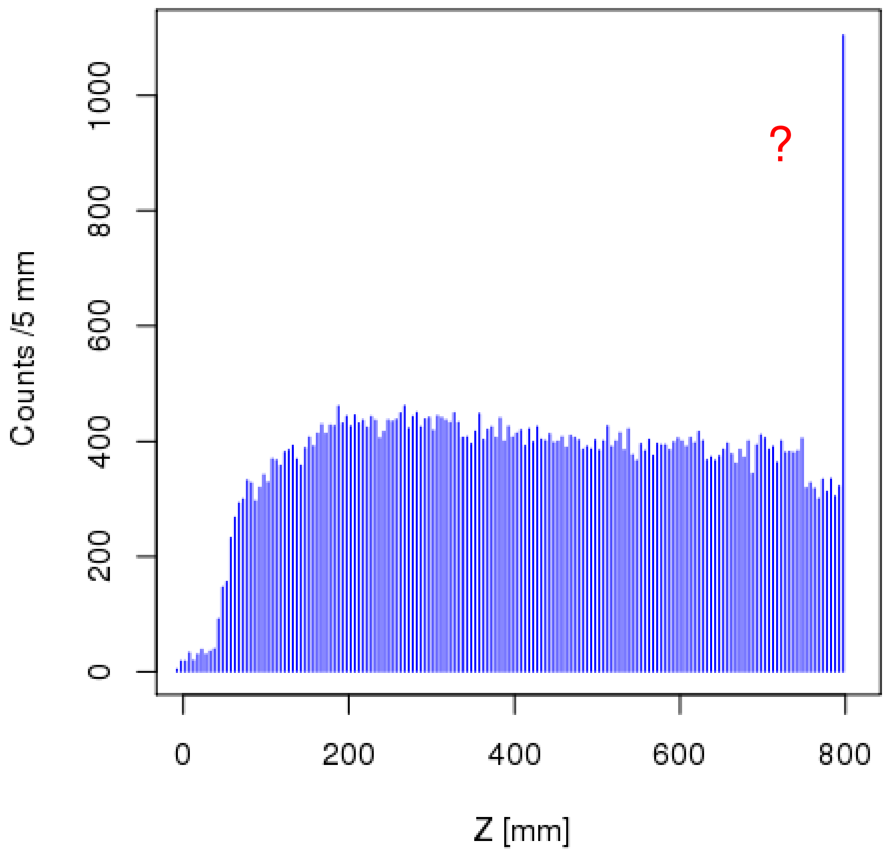


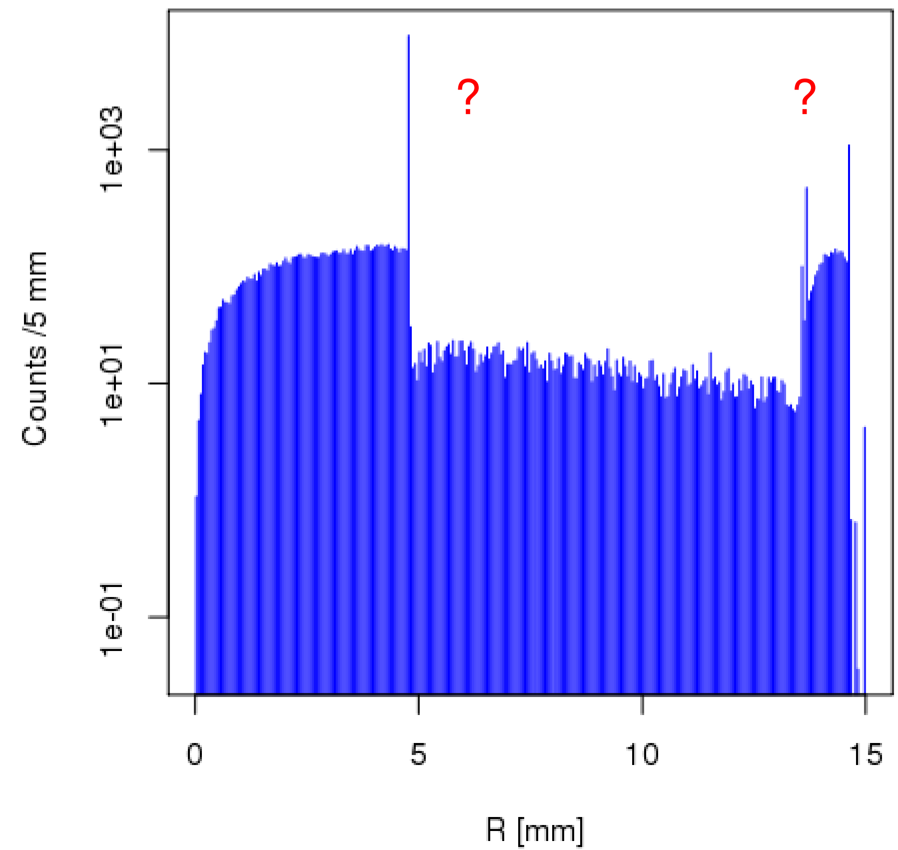
Better, but we still have a problem. !..

Next difference: Numerical integration of interaction probabilities and step length.

In both version. Not easy to fix, except by changing the geometry.

A look at the position where hadronic interactions occurs (for π^+) in the Be target (complete one)





Obtained with v4p8. But v4p9 (and I strongly suspect, v4.10) will produce the same peculiarity. Where do these spikes come from ? They are at the edges of the volumes..

Two possible models:

(I) Pions are Chameleons particle: their coupling to Be (or air) depends on the local density of matter. Inside the material, the interaction is screened, but once they emerge to much less dense medium, they interact, as the scattering amplitude is related to the change of density.

(ii) This is imply the way G4 does the tracking and handle multiple processes. It is slightly different in v4p9, with respect to older version of G4. In v4p9, prior to initiate the tracking, a set of probabilities are upload, one for each discrete process. In the case of decay, it will be related to the number of life time, for scattering, to the normalized mean free path. For each step, one decrements this “life time” by the physical time it took to go through the step, of by the physical number of interaction length. Any given step always occurs in a given medium, and the physical mean free path is computed, once per step, based on the set of cross-section, atomic numbers, and so forth.

If the clock ran out at the end of the step, the discrete process kicks in, and the process name is transferred to the user. But the position of the track is the position at the end of the step. The step length is often dictated by the geometry.. Hence, edges of volumes.

Further notes

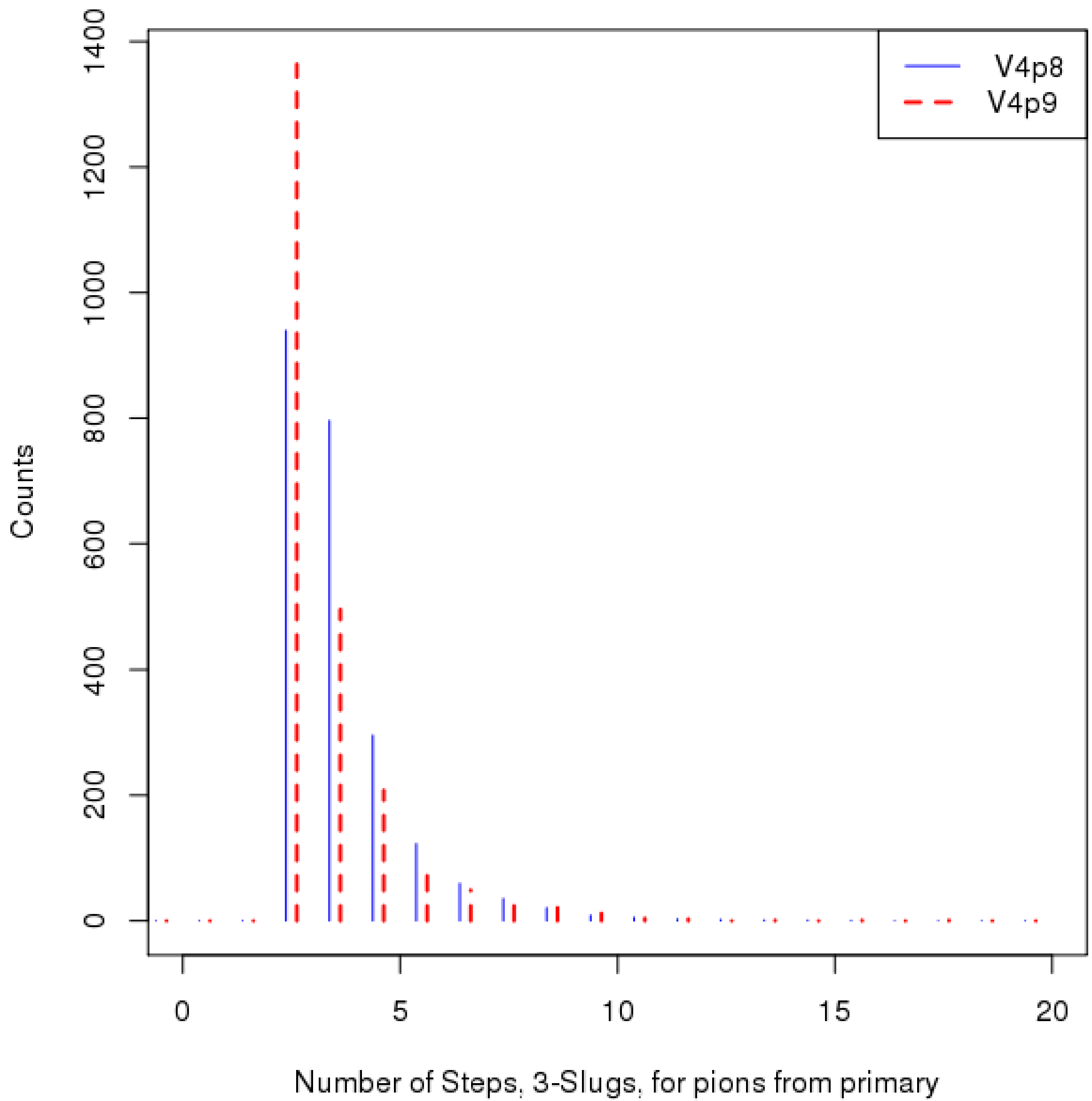
(I) Step lengths are discrete. This is a numerical integration.

(ii) The physical mean free path may depend on momentum. In case of (extremely) resonant scattering, occurring only with a narrow momentum range, G4 might severely "under-simulate" such scattering event, because, upstream of the step, the momentum is too low, and, if the step is too large, the momentum for the next step will too high. In this limit, not interaction at all, independently on how big the X-section is, on resonance.

Let us test the implication of this intrinsic numerical integration approximation: first, increase the inelastic scattering in Be by a factor five, to get more scattering events. Note that this X-section depends on momentum, between 0.5 and a few GeV. Run the with default geometry. Second, place small cylinders of Beryllium, 4.5 mm long, in the Be slugs, thereby forcing the step length to be smaller, as dictated by the transport mechanism. (We no longer have the option of setting a maximum length in G4). This exercise is done in v4p9.

The "measured" cross-section, as tallied by the number of π^+ inelastic scattering events, changed by 4.1%, for the nominal target geometry (full length target).

For this to be relevant, the step lengths in v4p8 and v4p9 must differ.



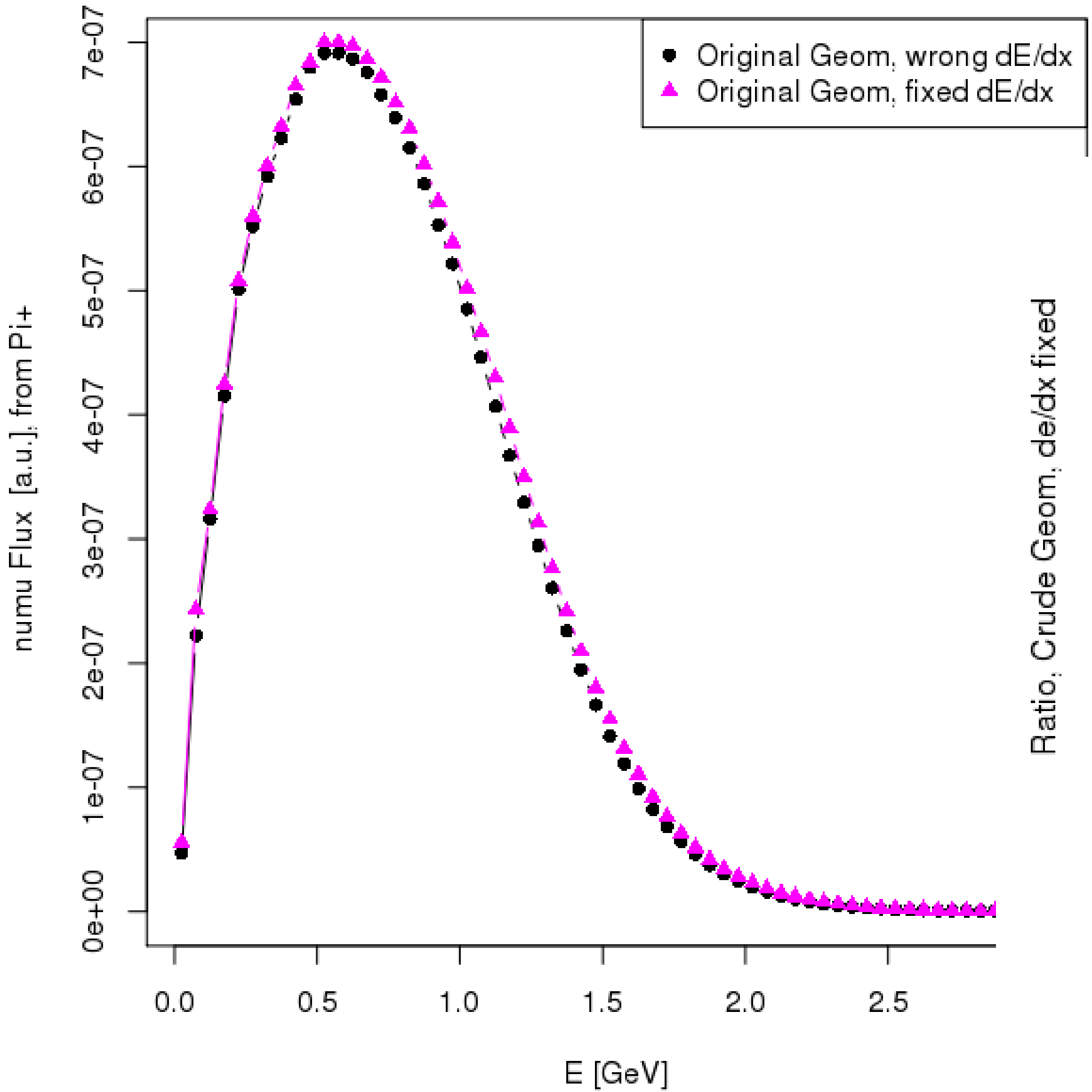
These are two (weighted, as usual) histogram of the number of steps G4 takes, moving the pion from the primary vertex to the place where the hadronic interaction occurs.

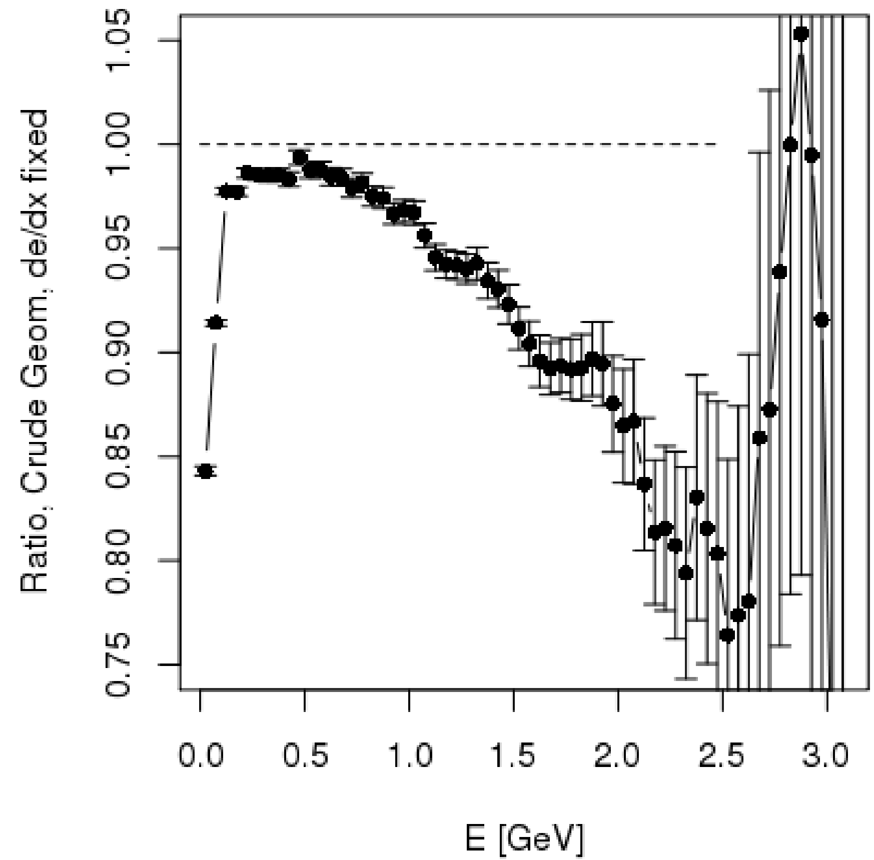
For short distance, v4p9 seems to be a bit more efficient... Shorter, fewer number of steps

Note: setting the maximum step length in G4 is no longer an option..

However, one can always redefine the

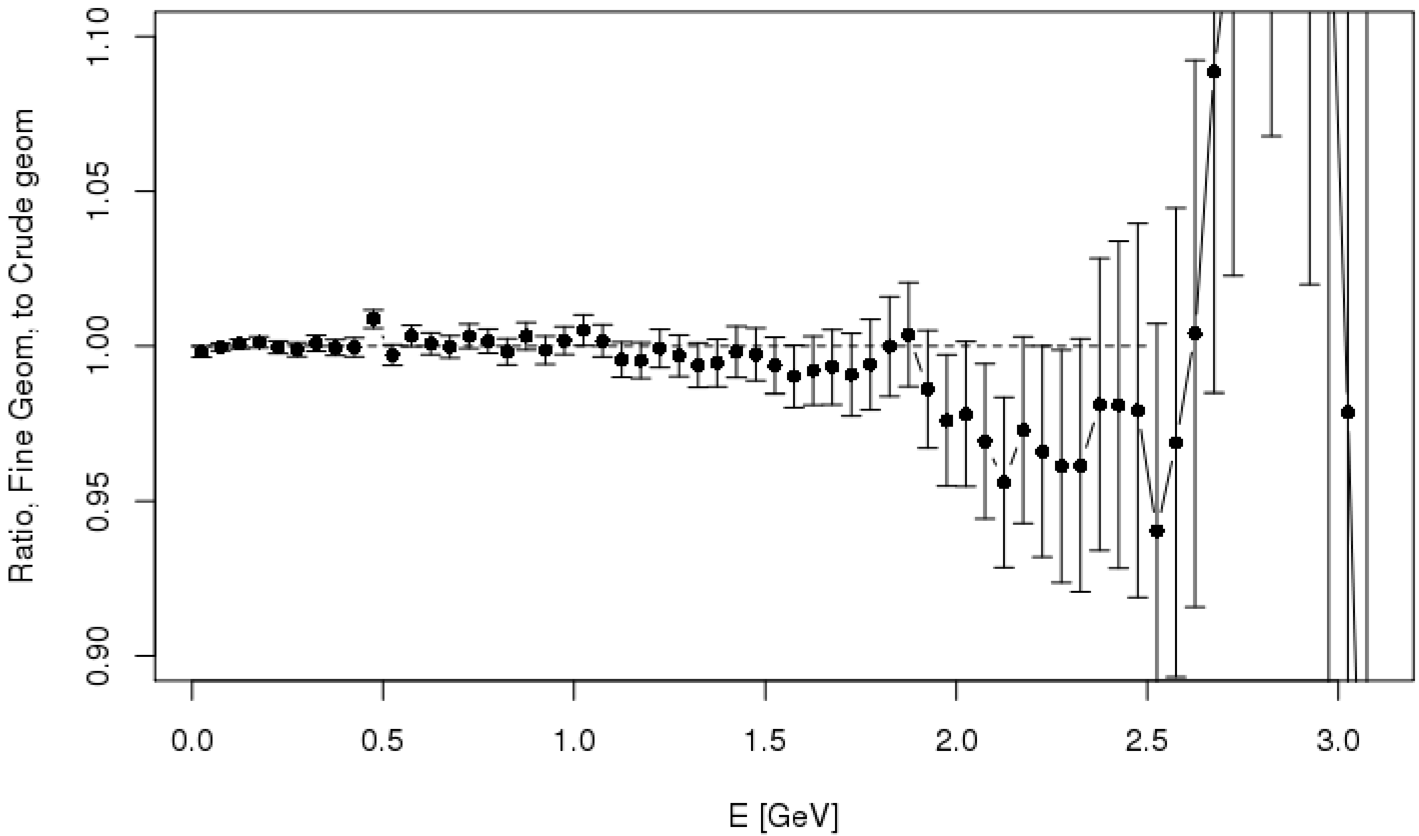
O.K. This will be hard to fix! It is an intrinsic limitation of the G4. Let us re-cap, and test the impact of a “fine grained” geometry on the neutrino spectrum. (and the correction on de/dx)





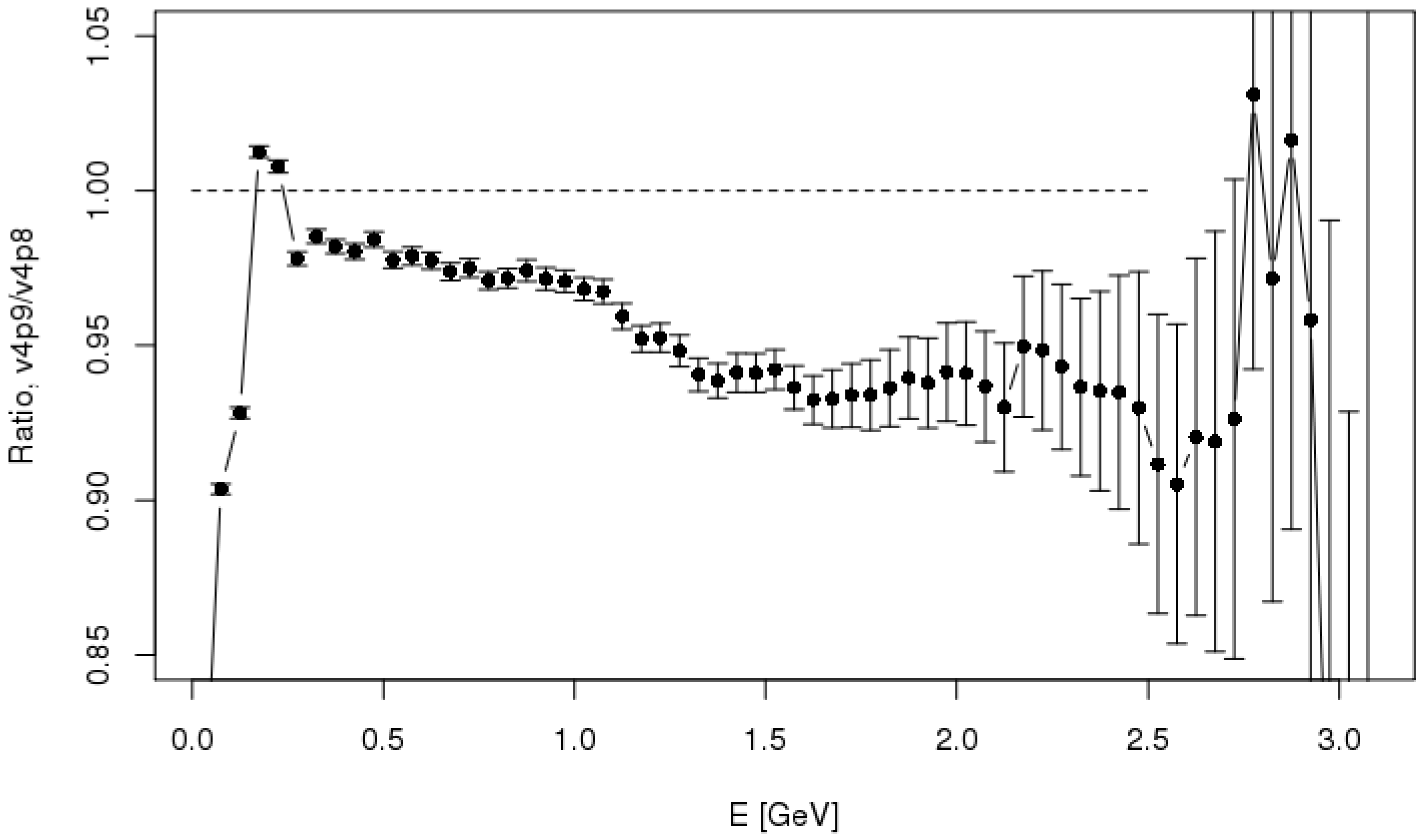
By doubling de/dx, we reduce the momentum of pions prior to decay... We get a bit more flux.. Note the large effect at high energy, probably due energy loss in the collimator.

Effect of the change in geometry in the Beryllium only...



Smaller than the de/dx correction...

Current ratio of ν_μ flux from π^+ decay, v4p9/v4p8 (after dE/dx correction)



Current level of discrepancy at 1.0 GeV = 5%   Still a discrepancy at low energy..
Systematic uncertainties due to modeling of the scattering processes (Cross-section + model) is still with us.

Progress... One bug resolved.. Learned lesson: To “Inherit” from very complex (and changing) code (G4 Physics list) should not be done lightly.

Back 15 years ago, Geant4 users were encouraged to write their own PhysicsList, allowing full flexibility in selecting which process physics they think is relevant to work with. However, the public/private interfaces was never easy to understand and control. Moreover, some of the processes are correlated with others.

With Geant4.10, it is very strongly advised to (I) use the existing physics list (ii) if a process needs revision, such, as for instance, pion scattering on Be, Al, Iron, etc, work in close collaboration with the G4 physics group.